Coastal Mixing

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LONG TERM GOALS

I seek to understand the mechanisms of turbulence and mixing in shallow water sufficiently well to be able to specify useful parameterizations for coastal circulation models.

OBJECTIVES

I believe that this goal can best be achieved through a combination of comprehensive measurement of the turbulent fluctuations, the larger scale flows that drive them and modelling. These turbulent flows are often complex and rapidly changing and can be only properly measured using a combination of methods that measure a variety of spatial and temporal scales. My medium-term scientific objective is to make and analyze such measurements in cooperation with other investigators.

APPROACH

My technical approach is to combine neutrally buoyant Lagrangian floats, acoustic remote sensing of various types, microstructure measurements and rapid CTD profiling. This instrumental suite can both map a given flow and determine its mixing rates.

During the last few years, I have developed a new type of neutrally buoyant float (see picture on right) designed to be used in energetic turbulent flows such as those found in the top and bottom boundary layers of the ocean. A combination of accurate ballasting, compressibility matched to that of seawater and high drag is used to make these floats follow the motion of water parcels accurately. The floats measure their depth and are acoustically tracked in the horizontal and thus produce measurements of vertical and horizontal velocity. They measure the temperature and vertical vorticity (from spin rate) of the water surrounding them. We have made about 250 deployments of these floats, in a wide variety of turbulent coastal and open ocean environments. Analysis of this data has been conducted by the PI, by Ren-Chieh Lien and by students supported by NSF.

WORK COMPLETED

A major task over the past few years has been to develop techniques for extracting well-defined turbulent quantities from Lagrangian data. This is necessary because these are, to my knowledge, nearly

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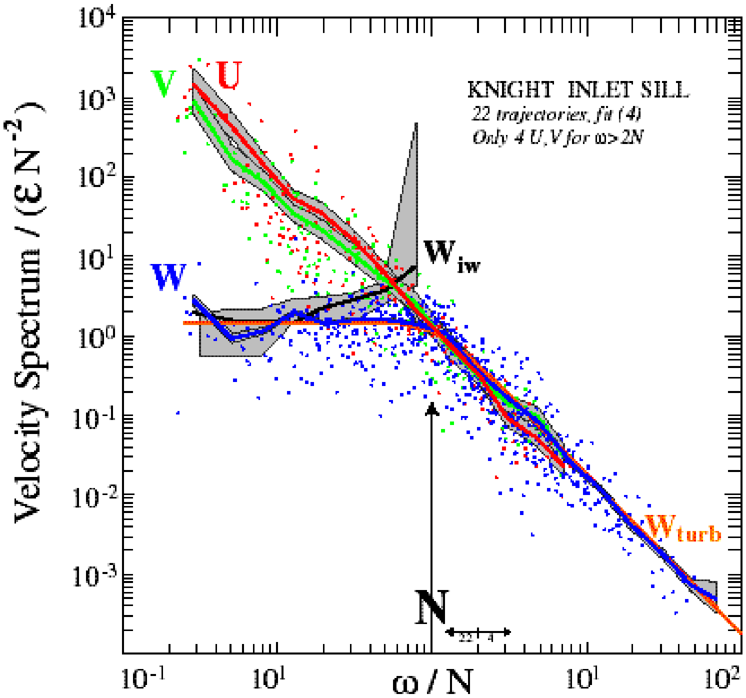
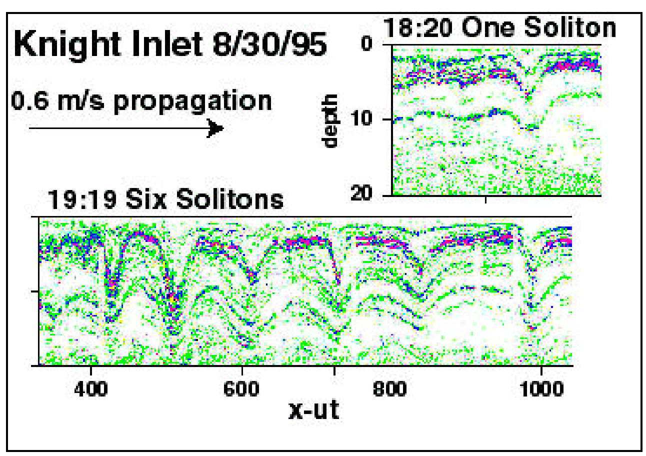
the first detailed Lagrangian measurements made in high-Reynolds' number flows. A paper, describing in detail the Lagrangian spectra of vertical velocity and vorticity in high Reynolds number turbulence and explaining it using concepts from homogeneous turbulence theory has been published the *Journal of Fluid Mechanics*. We find that the spectra have a universal shape in turbulent flows from which we can extract the rate of energy dissipation by the flow.



For FY98 a major task has been to extend these analyses to stratified fluids using 1995 data from Knight Inlet. The main result is shown in the Figure. For Lagrangian frequencies $\omega > N$, the buoyancy frequency, the data are consistent with **turbulence**: the velocity is nearly *isotropic* since the three velocity components (U,V,W) have similar energy, and the spectral slope is -2, which is the signature of the ***inertial subrange*** of unstratified turbulence. For $\omega < N$ the data are consistent with **internal waves**: the velocity is highly *anisotropic*, there is more horizontal kinetic energy (U,V) than vertical (W), and the ratio of vertical to horizontal energy varies with frequency in agreement with the usual ***consistency relation*** (W_{iw}, black line) for internal waves. We therefore conclude that waves and turbulence can be separated using Lagrangian frequency. Much of our work during FY98 has involved checking these data and extending the frequency range of the analysis. A paper describing these results has been submitted to the *Journal of Physical Oceanography*.

The form of these spectra implies a **new parameterization** for stratified turbulence relating the energy in the waves and the turbulent mixing rate. For sufficiently energetic flows we find $e = w^2 N$; the rate of kinetic energy dissipation, ε, is proportional to the mean vertical kinetic energy in the waves and the stratification N. This should apply for internal wave fields about 10-20 times more energetic than the open ocean Garrett-Munk levels. We are currently conducting a careful comparison of this prediction with other parameterizations.



The other major task during FY98 has been a continuing analysis of solibore data taken in Knight Inlet. The figure shows the evolution of a packet of solibores propagating away from the Sill at Knight Inlet as measured by an acoustic echosounder. The packet evolves from having a single wave to 6 or more waves an hour later. After another hour, the number has decreased to about 5. These data stand in strong contrast to

the usual assumption of rank-ordered, i.e. tallest first, slowly spreading waves. Other analysis has concentrated on intrusive solibores as described at the Knight Inlet web site *http://poseidon.apl.washington.edu/~dasaro/Solibore/start.html.*

RESULTS

It appears that stratified flows may be modelled as the sum of nearly isotropic turbulence and strongly anisotropic internal waves. All of the anisotropy is due to the internal wave component. For sufficiently strong turbulence, a simple relationship between the wave vertical kinetic energy and turbulence level exists which can provide a simple parameterization of the mixing rates.

IMPACT/APPLICATIONS

Accurate models of internal waves and turbulence are crucial for modelling shallow water circulations. Proper distinction between waves and turbulence is crucial for making such models, as are parameterizations of these processes.

TRANSITIONS

None

RELATED PROJECTS

These floats are close relatives of those used to study deep convection in the Labrador Sea funded by ONR 322OM. The same instruments have been used to study upper ocean mixing processes under NSF support. Mixing processes in these various environments are similar in many ways and we learn the most by comparing and contrasting them.

PUBLICATIONS

Lien, R.C., E. A. D'Asaro, G.T. Dairiki, 1998,

Lagrangian Frequency Spectra of Vertical Velocity and Vorticity in High Reynolds' Number Oceanic Turbulence, *J. Fluid Mech*., 362,177-198

Lien, R.C. and E. A. D'Asaro, 1998, Lagrangian Measurements of Waves and Turbulence in Stratified Flows, submitted to *J. Phys. Oceanogr.*